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Influence of Grazing Intensity on Seed Bank of a Sandy Grassland in Horqin Steppe of China

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Abstract: It is well known that grazing influences the quantity and quality of grassland seed banks, and that the magnitude of influence depends on the grazing intensity and the bioclimate zone in which the grassland is located. However, very little is known about seed bank dynamics under different grazing intensities in a sandy grassland of Horqin Steppe. In this study four grazing intensity treatments, i.e., control (ungrazed, CK), light grazing (2 sheep unit ha^{-1}, L), moderate grazing (4 sheep unit ha^{-1}, M), and heavy grazing (6 sheep unit ha^{-1}, H), were imposed on a sandy range site. The results showed that: (i) with the increase of grazing intensity, the number of plant species in the seed bank decreased, but the percentage of annual species increased; (ii) the number of seed bank under both light grazing and moderate grazing tended to increase, but under heavy grazing it tended to decrease; (iii) annual species dominated the seed bank, and with increased grazing intensity, the percentage of the number of seeds of annual species decreased, but that of leguminous plants increased; (iv) under the ungrazed and light grazing conditions the seed density in soil showed a significant correlation with the corresponding plant frequency in the vegetation, whereas under moderate and heavy grazing conditions such correlation was poor.

Key words: The Horqin Steppe, seed bank, seed density, seed composition, species composition.

There exists a direct relationship between seed bank and vegetation dynamics of a plant community, and this kind of relationship is an important aspect in the study of ecological rehabilitation of degraded rangelands. Recently the study on seed bank has increasingly attracted attention of ecologists around the world (Hodgson and Grime, 1990). Many studies show that seed banks obviously reflect temporal and spatial changes (Thompson, 1978, 1986; Rundel and Gibson, 1996; Guo *et al.*, 1998). The abiotic factors affecting the temporal and spatial patterns of seed bank include wind regime, landform, soil condition, etc. (Thompson and Grime, 1979; Liddle *et al.*, 1987; Okubo and Levin, 1989; Reichman, 1984; Chambers, *et al.*, 1991; O'Connor and Pickett, 1992; Chambers and MacMahon, 1994), whereas the biotic factors include seed shape, seed size and behavior of seed-eating animals, grazing, etc.

Grazing is an important factor influencing seed bank of grasslands. It affects not only the quantity of seeds, but also the quality of seeds in a seed bank (Simpson *et al*., 1989; Kinucan and Smeins, 1992). However, there exists great difference, even opposite views, as to how grazing influences seed bank (Thompson, 1978; O'Conor and Pickett, 1992; Ghermand, 1997; Major and Pyott, 1966; Harper, 1997; Russin *et al*., 1992). The Horqin Steppe, as a typical temperate degraded grassland (Liu *et al*., 1996) in the agropastoral zone of northern China, suffers from severe desertification (Zhu and Chen, 1994). In recent years, some studies on the influence of grazing on vegetation have been made (Zhao *et al*., 1997,1999a, 1999b; Li *et al*., 1999), but very little study has been carried out on the seed bank and the influence of grazing on soil seed bank in this kind of sandy range.

This paper reports studies on the influence of four grazing intensities on the grassland seed bank. The objectives of this research were to determine: (i) the influence of grazing intensities on species composition and the quantity of seeds in seed bank of the sandy grassland, and (ii) relationship between the seed density in the soil and the associated vegetation under four grazing intensities.

Study Site and Methods

Study site

Research was conducted at Daliushu village in the south-east part of Naiman Banner of Inner Mongolia Autonomous Region, belonging to the Horqin Steppe (42°58′N and 120°43′E) with an elevation of 345 m (Fig. 1). The annual average temperature of the study area is 6.4°C with January the coldest month averaging –13.1°C, and July the warmest averaging 23.7°C. The 10°C accumulative temperature is 3000 to 3400°C. Mean annual precipitation is 362 mm, of which 65% is received in June, July and August. Annual evaporation is 1935 mm. Annual mean wind velocity is 3.5 m s^{-1} and the number of gale days is 20 to 60. Soil is dominated by blown sand with coarse texture and loose structure.

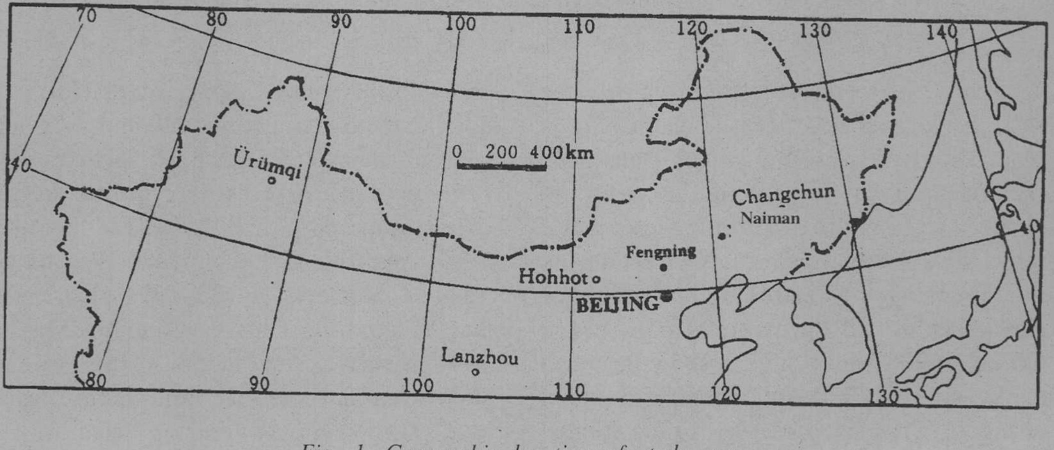

Fig. 1. Geographic location of study area.

The zonal vegetation represents a transition zone between dry steppe and meadow steppe with some perennial monocotyledonous species and *Ulmus pumila* and *Prumus sibrica* as dominant species under undisturbed conditions (Liu *et al.*, 1996). However, under present disturbed condition it is dominated by psammophytes, including some *Artemisia* species, perennial monocotyledons and annuals like *Agriophyllum squarrosum*, *Artemisia halodendron*, *A. scoparia*, *Lespedeza davuria*, *Cleistogenes squarrosa*, *Leysmus secalinus*, *Setaria viridis*, etc.

Experimental design and treatments

An area of 6.4 ha, marked out in the free grazing, natural, sandy range, was enclosed and divided into four 75 x 200 m paddocks by internal fencing. Four grazing intensity treatments were: (1) control (ungrazed, CK), (2) light grazing (2 sheep unit ha^{-1}, L), (3) moderate grazing (4 sheep unit ha^{-1}, M), and (4) heavy grazing (6 sheep unit ha^{-1}, H). Sheep were allowed to graze on the site from June, 10 to September, 20 each year and it continued for 5 consecutive years. In the sixth year the measurements of seed bank of different treatments were taken.

A transect (south-north direction) was selected across the central part of each paddock. Fifteen soil sample cores were collected along each transect at an interval of 12 m in early April before seed germination, and the number of total sample cores was 60. Each core was 20 cm long, 20 cm wide and 5 cm deep. These undisturbed soil samples were incubated under natural light from April to August in a greenhouse that did not have temperature control. The seedlings were identified, counted and removed at 3-day interval, and water was added daily to keep the soil moist. In addition, in late growing season (August) one 1 x 1 m quadrate near each sampling point was selected to count the number of species, and the total number of quadrates was 60. Using seedling emergence to qualify the soil seed bank tends to underestimate the seed bank if germination requirements are not met (Robert, 1981), but it does provide an estimate of readily germinable fraction of seed bank (Gross, 1990).

Data analysis

Except for the data on the species frequency in vegetation, other data were logarithmicly transformed before analysis. Multi-Dimensional Sphere Model (MDSM) was employed to determine the trend of seed density of all species dynamics under three grazing intensities, i.e., light grazing, moderate grazing and heavy grazing. Vector length was considered as sum of the vector projected by all species in multi-dimension space to a super sphere, and it was calculated with $\sqrt{(x_1^2+x_2^2+...+x_n^2)}$, where x is the average value of seed bank density. State Vector Dimension (SVD) was obtained with average density divided by Vector length, and T with average seed bank density at a certain grazing intensity divided by the average density under ungrazed condition. Trend index is the average of T of all species (Bai *et al.*, 1995). The correlation between the seed number in seed bank and the corresponding plant species frequency in vegetation was analyzed by means of Mini-table software. The number of species in vegetation is the cumulative number of species in 15 quadrates at each treatment.

Results

Trend analysis of seed bank

Trend index is a reflection of dynamics of seed density in soil bank. If it is more than 1, the seed density tends to increase inversely, if it is less than 1, the seed density tends to decrease. Compared with density under control, trend indices at both light and moderate grazing were 1.11 and 2.42, respectively, whereas that under heavy grazing was 0.93 (Table 1). Therefore, trend analysis showed that seed density under both light and moderate grazing increased, while that under heavy grazing declined.

SVD reflected the relative importance of species in seed bank. As can be seen from Table 1, the SVD-ranked first three were *A. scoparia*, *A. sieversiana*, and *S. viridis* under control treatment, *A. scoparia*, *A. sieversiana* and *A. adscensionis* under light grazing treatment, *Lespedeza* spp., *A. adscensionis* and *A. scoparia* under moderate grazing treatment, and *Lespedeza* spp., *A. scoparia* and *A. adscensionis* under heavy grazing treatment (Table 1).

Quantitative characteristics of seed banks

The number of seeds that germinated in soil under moderate grazing treatment was the highest, and the density averaged 5352 (SE±726) seeds m^{-2}, which was followed by 3314 (SE±739), 3684 (SE±739), 2002 (SE±720) seeds m^{-2} under control, light grazing and heavy grazing, respectively. Percentage of the number of seeds of annual species decreased from 95.3 to 66.0%, whereas the number of seeds of leguminous species increased from 2.4 to 43.5% with increasing grazing intensity (Table 2).

Under light grazing intensity the number of species in the seed bank was roughly the same as that under the control treatment, whereas that under moderate and heavy grazing conditions tended to decline (Table 3). With increasing grazing intensity the percentage of the number of annual species increased, but the number of perennial species decreased (Table 3).

The number of seeds of each species in the soil bank under ungrazed and light grazing treatments correlated significantly with the corresponding species frequency in vegetation ($r = 0.47$, $P<0.001$ and $r= 0.39$, $P<0.005$, respectively), whereas such correlation under moderate grazing and heavy grazing conditions was poor.

Discussion

There are mainly three views on the influence of grazing on seed density in the soil bank. Firstly, grazing can increase seed density of grassland. For example, under the marine climatic condition, frequent and heavy grazing increased seed density (Thompson, 1978). But in the Savanna region seed density was highest under light grazing condition (O'Conner and Picket, 1992). Mediterranean climate, as well as the temperate grasslands (Harder 1977) showed similar results. Secondly, grazing can reduce seed density. For example, Ghermandi (1997) studied the seed bank of the grassland in the Patagonia region of South America with precipitation of 800 mm and concluded that grazing reduced the seed density of the grassland. Also Johnson *et al.* (1969) studied the Alberta grassland in Canada and drew a similar conclusion. Thirdly, grazing has no

Table 1. Dynamic trend anlaysis of seed density through MDSM

Species	Control		Light grazing			Moderate grazing			Heavy grazing		
	Av.	SVD	Av.	SVD	Trend	Av.	SVD	Trend	Av.	SVD	Trend
Aristida adscensionis	0.984	0.19	1.853	0.33	1.88	2.86	0.34	2.91	2.25	0.38	2.29
Artemisia lavandulaefolia	0.954	0.19	0	0.00	0.00	0.00	0.00	0.60	0.10	0.10	0.63
Artemisia scoparia	3.185	0.62	3.328	0.60	1.04	2.75	0.32	0.86	2.28	0.39	0.72
Artemisia sieversiana	1.754	0.34	1.954	0.35	1.11	1.55	0.18	0.88	1.49	0.25	0.85
Bassia dasyphylla	0.195	0.04	0.27	0.05	1.38	2.42	0.29	12.43	0.16	0.03	0.79
Chenopodium spp.	0.597	0.12	0.165	0.03	0.28	0.00	0.00	0.00	0.00	0.00	0.00
Chloris virgata	0.3	0.6	0.223	0.04	0.74	1.69	0.20	5.62	1.12	0.19	3.75
Cleistogenes squarrosa	0.82	0.16	0.436	0.08	0.53	1.69	0.20	2.05	0.23	0.04	0.28
Corispermum spp.	1.256	0.24	1.083	0.20	0.86	1.72	0.20	1.37	0.54	0.09	0.43
Digitarta sanguinalis	0.378	0.07	0.3	0.05	0.79	2.46	0.29	6.52	0.96	0.16	2.55
Eragrostis poaeoides	0.501	0.10	0.28	0.05	0.56	1.67	0.20	3.33	1.82	0.31	3.64
Erodium stephanianum	0.406	0.08	0.135	0.02	0.33	0.00	0.00	0.00	0.27	0.05	0.67
Euoporbia humifusa	1.489	0.29	1.645	0.30	1.10	2.02	0.24	1.35	0.68	0.12	0.46
Euphorbia esula	0.301	0.06	0.301	0.05	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Ixeris denticulata	0.27	0.05	0.523	0.09	1.94	1.70	0.20	6.30	0.45	0.08	1.68
Lespedeza spp.	1.66	0.32	1.44	0.26	0.87	3.21	0.38	1.93	2.87	0.49	1.73
Leymus secalinus	0.183	0.04	0.708	0.13	3.87	1.30	0.15	7.10	0.00	0.00	0.00
Melissitus ruthenicus	0.41	0.08	0.31	0.06	0.76	0.00	0.00	0.00	0.00	0.00	0.00
Pennisetum centrasiaticum	0.301	0.06	0.135	0.02	0.45	0.00	0.00	0.00	0.00	0.00	0.00
Phragmites australis	0.588	0.11	0.83	0.15	1.41	0.00	0.00	0.00	0.00	0.00	0.00
Portulaca oleracea	0.28	0.05	0.42	0.08	1.50	1.01	0.12	3.59	0.00	0.00	0.00
Potentilla bifurca	0.135	0.03	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Salsola collina	1.182	0.23	1.45	0.26	1.23	2.21	0.26	1.87	2.11	0.36	1.78
Setaria viridis	1.694	0.33	1.341	0.24	0.79	2.45	0.29	1.45	1.66	0.28	0.98
Tribulus terrestris	0.12	0.02	0.21	0.04	1.75	0.00	0.00	0.00	0.00	0.00	0.00
Length	5.15	1.00	5.55	1.00		8.50	1.00		5.90	1.00	
Trend index					1.11			2.42			0.93

significant influence on the seed bank of grassland. For example, Kinucan and Smeins (1992) and Milberg and Hansom (1993) reached conclusions that grazing had no significant influence on the seed density, although it caused the changes in seed composition.

The first reason for different results in the above mentioned investigations is that the grasslands studied belonged to different climatic conditions, and ranged from marine climate grassland (Thompson, 1978), to Mediterranean grassland (Major and Pyott, 1966; Russi *et al.*, 1992), temperate grassland

Table 2. Quantities of seed in the seed banks under four grazing intensities

Treatment	Seed density (seeds m^{-2})	Annuals' seeds (%)	Leguminous seeds (%)
Control	3314±739	95.3	2.4
Light grazing	3684±600	94.3	3.3
Moderate grazing	5352±726	67.1	30.3
Heavy grazing	2002±720	66.0	43.5

(Harper, 1997), Savanna (O'Conner and Pickett, 1992) and cold zone grassland (Johnson *et al.*, 1969). The second reason is that different researchers used different grazing gradients in their experiments. For example, Russi *et al.* (1992) used the following grazing gradients: light grazing intensity of 0.8 to 1.1 sheep units ha^{-1} and heavy grazing intensity of 1.7 to 2.3 sheep units ha^{-1}. Ghermandi's conclusion was based on the comparison between free grazing and controlled grazing. Our experimental results showed that for the typical sandy grassland in China, 2 sheep units ha^{-1} and 4 sheep units ha^{-1} of grazing tended to increase number of seeds, while under 6 sheep units ha^{-1} of grazing condition the number of seeds in the seed bank tended to decline.

Grazing influences the qualitative and quantitative composition of seed bank (Kinucan and Smeins, 1992). However, different grazing gradients had different influences. In the Horqin Steppe, compared with ungrazed, the number of plant species in the seed bank was unchanged, under light grazing condition but under moderate and heavy grazing the number of species sharply decreased. In addition, with the increase of grazing intensity, the percentage of the number of annual species in the seed bank increased, and that of perennial monocotyledonous species decreased. The reason for the decrease in the number of seeds of perennial monocotyledonous species may be that reduction in the vegetation cover caused by grazing and trampling of animal, favored burial of seeds of annual species (Harper, 1977). That the biomass of vegetation on the sandy grassland decreases and the palatable parts of the perennials are eaten before maturity may be another possible reason. In this case, there is no seed production and the soil seed bank is not replenished. Hence the seeds in soil bank are gradually depleted.

Table 3. The number of species in seed bank under four grazing intensities

Treatment	Number of annual species	Number of perennial species	Number of total species	Percentage of annuals
Control	19	6	25	76.0
Light grazing	20	5	25	80.0
Moderate grazing	13	3	16	81.3
Heavy grazing	14	2	16	87.5

In general, the main contributors to seed banks in different grasslands of the world are annual dicotyledonous species (Major and Pyott, 1966; Roberts, 1981). In the Horqin Steppe, the seeds of annual species such as *A. scoparia*, *Setaria viridis*, *Aristida adscensions* and *Corispermum hyssopifolium* dominate the seed bank of the sandy range. With increasing grazing intensity the percentage of the number of annual seeds decreased, wheras the number of seeds of leguminous plants increased. The reason for this may be that the reduction of vegetation cover of the grassland caused by grazing provided a variable condition for the seed production of the legume creeper *Lepedeza* that has high seed production capacity and poor palatability.

There was a significant correlation between the number of seeds in soil banks and plant frequency in ungrazed and light grazed conditions, but in moderate and heavy grazing conditions such correlation was poor. This is in accordance with the results in the Savanna (O'Conner and Pickett, 1992), but different from the results in most other grasslands (Thompson and Grime, 1979).

In conclusion, light grazing and moderate grazing tend to promote seeds in soil banks, whereas heavy grazing tends to hamper seeds in soil banks. The number of seeds in soil banks correlates significantly with the frequency of species in vegetation only under the ungrazed and light grazing conditions.

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